Optimisation of CO2 laser-produced Sn plasmas for next generation semiconductor lithography sources

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1.Introduction

• Research to date [1] has identified CO_2 laser produced plasmas (LPPs) of Sn as a viable Extreme Ultra-violet Lithography (EUVL) source candidate

• CO_2 LPPs have demonstrated an increased in-band conversion efficiency (CE) when compared to the Nd:YAG, due in the main to reduced opacity effects [2]

• Pulse shortening techniques of the CO_2 temporal profile have been reported [3] along with CE values of 3-4% [4], however theoretical modelling has shown the potential to improve this figure

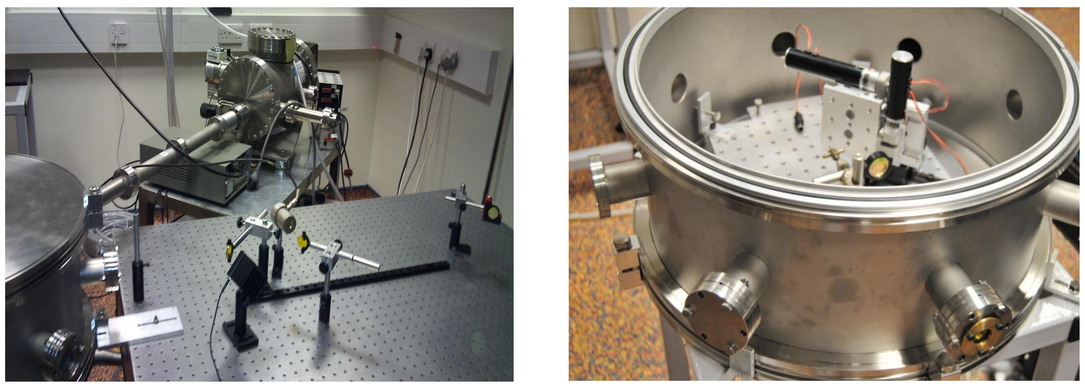

Figure 1(a) & (b): *Images of lab layout and inside the chamber*

3.Results

• By varying the lens position, the on target power density was also varied and the CE as a function of focus is shown

• Fig. 3 and 4 show variation between the CE values obtained at 45° and 90° to target normal were observed

• Through varying the gas mixture in the laser chamber, 5:2:3 of $He:CO_2:N_2$ was found to demonstrate the highest CE with a maximum at 2%

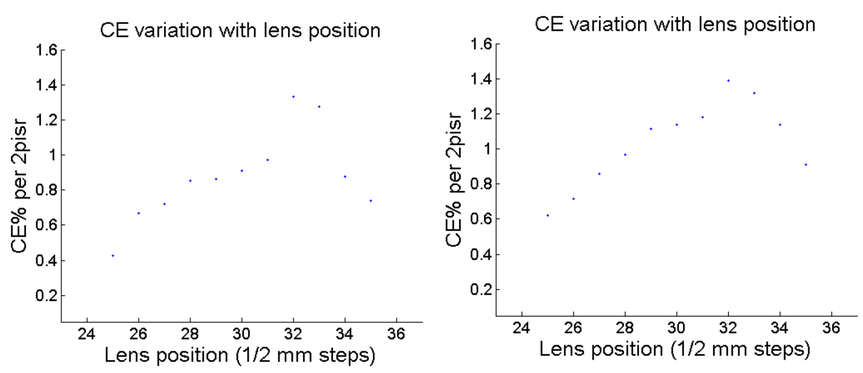

Figure 3(a) & (b): *CE with different lens positions for 6:1:3 and 5:2:3 mixes at 45° to target normal*

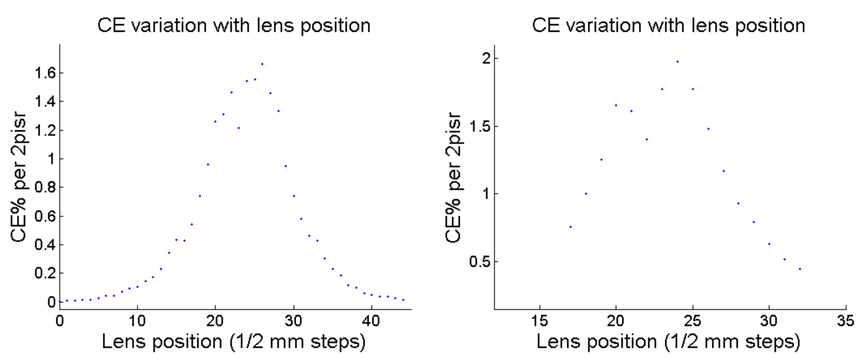

Figure 4(a) & (b): *CE with different lens positions for 6:1:3 and 5:2:3 mixes at 90° to target normal*

• CE results presented were less than reported and theoretical values

• A novel plasma shutter was designed and implemented which, when adjusted, clipped the N_2 tail from the typical CO_2 laser temporal profile and allowed control over the duration of the pulse, the results of which are shown in Fig. 5-10

• Pulse duration of 2-50ns achieved with energies from 20-700mJ

• Fig. 7 and 10 shows a reasonable agreement between the measured pulse lengths and calculations using a simple laser heating model [5]

2.Experimental set-up

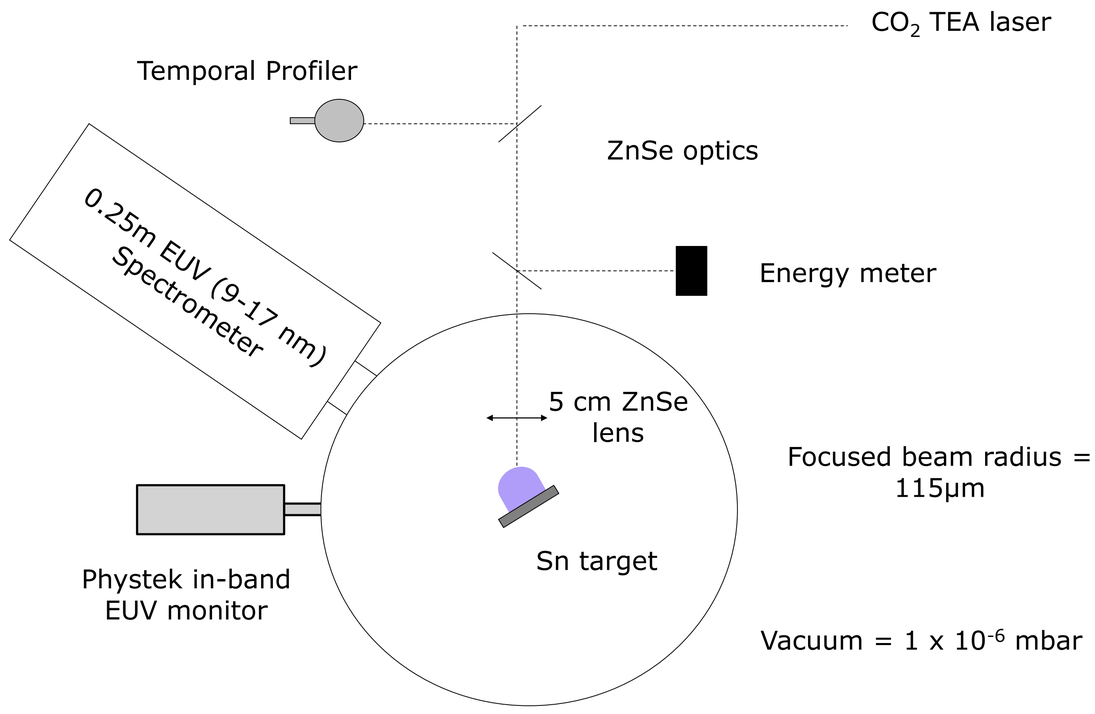

Figure 2: *Laboratory set-up for obtaining EUV spectra at 90° to target normal and EUV monitor at 45°*

• Fig. 1 and 2 shows the set-up used to acquire EUV spectra. A TEA CO_2 laser delivering up to 400mJ in 50ns, at a wavelength of 10.6μm was used to irradiate the target

• Temporal profile and pulse energy were measured for each shot due to variation in the laser from pulse to pulse. Spectra produced with the EUV spectrometer at 45° to target normal.

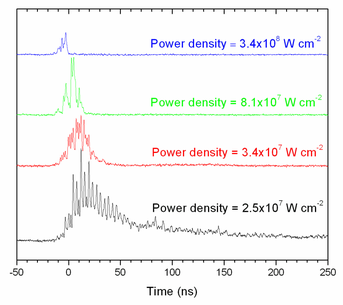

Figure 5: *Shortened pulse profiles*

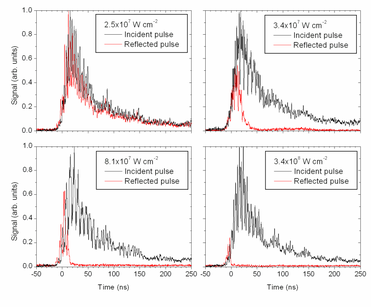

Figure 6: *Shortened pulses with original profiles*

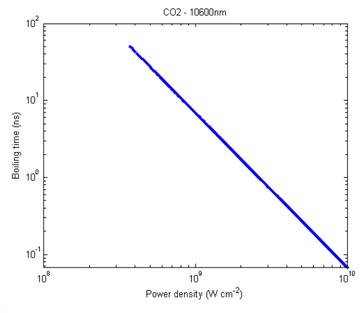

Figure 7: *Calculated surface boiling times*

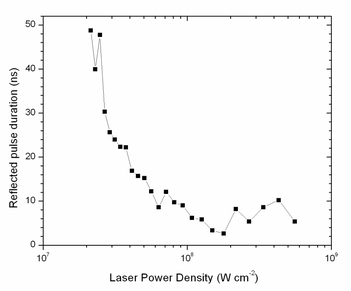

Figure 8: *Shortened pulse durations*

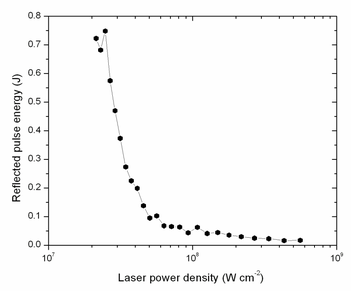

Figure 9: *Shortened pulse energies*

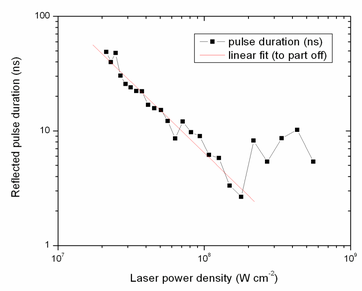

Figure 10: *Pulse durations with linear fit*

• Future work will consist of using these very short pulses to irradiate a range of targets including; solid Sn, mass limited Sn, novel target metals and plasma targets

4.References

[1] Y. Tao, M. S. Tillack, S. S. Harilal, K. L. Sequoia, and F. Najmabadi: "Investigation of the interaction of a laser pulse with a preformed Gaussian Sn plume for an extreme ultraviolet lithography source". *J. Appl. Phys.*, **101**, 023305 (2007)
[2] J. White, P. Dunne, P. Hayden, F. O'Reilly, and G. O'Sullivan: "Optimizing 13.5 nm laser-produced tin plasma emission as a function of laser wavelength". *Appl. Phys. Lett.*, **90**, 181502 (2007)
[3] N. Hurst and S. S. Harilal: "Pulse shaping of transversely excited atmospheric CO_2 laser using a simple plasma shutter". *Rev. Sci. Instrum.*, **80**, 035101 (2009)
[4] S. S. Harilal, T. Sizyuk, V. Sizyuk, and A. Hassanein: "Efficient laser-produced plasma extreme ultraviolet sources using grooved Sn targets". *Appl. Phys. Lett.*, **96**, 111503 (2010)
[5] V. N. Tokarev and A. F. H. Kaplan: "An analytical modelling of time dependent pulsed laser melting". *J. Appl. Phys.*, **86**, 2836-2846(1999)

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